Bloom evenness modulates the influence of bloom abundance on insect community structure in suburban gardens

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As land use change drives global insect declines, the value of enhancing habitat in urban and suburban landscapes has become increasingly important for flower-visiting insects. In order to help identify best landscaping practices, we conducted plant surveys and insect bowl-trap surveys in 34 suburban yards for 21 months in Florida, USA, which resulted in 274 paired days of plant and insect survey data. We assessed the impact of nearest greenspace size, distance to greenspace, yard area, plant richness, plant type, bloom abundance, bloom richness, and bloom evenness on insect abundance and richness. Our samples include 34,972 insects captured, 485,827 blooms counted, and 774 species of plants recorded. We found that bloom evenness had a modulating effect on bloom abundance — a more even sample of the same number of blooms would have a disproportionately greater positive impact on flower visitor richness, insect richness, and insect abundance. Bloom abundance was also highly significant and positively associated with flower visitor abundance, but nearest greenspace size, distance to greenspace, plant type (native vs. non-native vs. Florida Friendly), and yard area were not found to be important factors. Plant richness was a highly significant factor, but its effect size was very small.

1 **Bloom evenness modulates the influence of bloom abundance on insect community**
2 **structure in suburban gardens**

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30 **Abstract**

32 As land use change drives global insect declines, the value of enhancing habitat in urban and
33 suburban landscapes has become increasingly important for flower-visiting insects. In order to
34 help identify best landscaping practices, we conducted plant surveys and insect bowl-trap
35 surveys in 34 suburban yards for 21 months in Florida, USA, which resulted in 274 paired days
36 of plant and insect survey data. We assessed the impact of nearest greenspace size, distance to
37 greenspace, yard area, plant richness, plant type, bloom abundance, bloom richness, and bloom
38 evenness on insect abundance and richness. Our samples include 34,972 insects captured,
39 485,827 blooms counted, and 774 species of plants recorded. We found that bloom evenness had
40 a modulating effect on bloom abundance — a more even sample of the same number of blooms
41 would have a disproportionately greater positive impact on flower visitor richness, insect
42 richness, and insect abundance. Bloom abundance was also highly significant and positively
43 associated with flower visitor abundance, but nearest greenspace size, distance to greenspace,
44 plant type (native vs. non-native vs. Florida Friendly), and yard area were not found to be
45 important factors. Plant richness was a highly significant factor, but its effect size was very
46 small.

47 **Introduction**
48
49   Anthropogenic-driven land use and land cover changes are considered among the primary threats
50   to biodiversity and the fundamental productivity and sustainability of ecological systems
51   (Cardoso et al., 2020; Goulson, 2019; van Klink et al., 2020). Significant biodiversity
52   degradation is often most pronounced in urban areas due to the overall intensity of land
53   modification leading to high levels of direct habitat loss and increased habitat fragmentation
54   (Piano et al., 2020; Sánchez-Bayo and Wyckhuys, 2019). This in turn is commonly associated
55   with the loss of landscape connectivity, changes in species composition, increased biotic
56   homogenization, and the erosion of essential ecosystem services as well as innumerable other
57   stressors and drivers that may negatively affect wildlife. These stressors are reflected in global
58   insect populations, with one recent metastudy finding that terrestrial insect populations have
59   declined by 24% in the last 30 years (van Klink et al., 2020).
60
61   A driving force behind land cover change is urbanization. Today, more than half of the world's
62   people live in urban areas. As global population growth continues to accelerate, some 2.5 billion
63   more people are projected to be added to cities and urban centers by 2050 (United Nations
64   Department of Economic and Social Affairs, 2019). In the United States, over 80% of the
65   densification of humans and human activities is concentrated in cities, with U.S. developed land
66   area expected to increase by 40-90% in some locations (Boustan et al., 2013; Sleeter et al.,
67   2017).
68
69   While conservation efforts and research have historically focused on more intact, high value
70   natural areas, the utility, role and importance of urban green spaces for biodiversity conservation
71   are increasingly becoming recognized (Rupprecht et al., 2015). Concurrent with urban
72   population growth in the United States, the residential lawn landscape has grown to dominate the
73   suburban and urban landscape. Within this residential landscape, lawns dominate and occupy
74   nearly 40% of the total estimated 163,812 km^2 of turfgrass that covers approximately 1.9% of the
75   total area of the continental U.S. (Milesi et al. 2005). The non-turfgrass landscaped portion of a
76   typical yard, which includes trees, shrubs, and ornamental plantings, makes up only about 18%
77   of the total landscape (U.S. Census, 2009). Despite this potential limitation, human-dominated
78   environments can nonetheless be floristically diverse and harbor complex vegetation structure
79   (Sandström et al., 2006; Beninde et al., 2015; Threlfall et al., 2016).
80
81   Plant community composition, including the fine scale habitat heterogeneity often seen in urban
82   gardens, has been shown to influence insect community assembly. This has been particularly
83   well-demonstrated for insect groups, with many examples of its predictive or positive
84   correlations (Adams et al. 2020; Baldock et al. 2015, 2019; Theodorou et al. 2017). This close
85   linkage has important ramifications for the development of appropriate conservation strategies to
86   help maintain, increase or restore insect biodiversity in a variety of managed or degraded
87   landscapes, especially with the growing evidence of accelerated insect declines (Potts et al. 2010;
88   Forister et al. 2019; van Klink et al., 2020; Mathiasson and Rehan, 2020). Diverse insect
89   communities are important to ensure the provision of key ecosystem services (i.e. wildlife
90   nutrition, decomposition, natural pest control, and pollination) and promote ecosystem resilience
91   in the face of continued environmental change (Elmqvist et al. 2003).
92

93   Understanding which variables within an urban landscape can most impact insect populations is
94   important for conserving insect diversity in home gardens and yards, municipal parks and
95   greenspaces, and other built environments. Efforts to increase insect pollinator and other
96   arthropod assemblages in urban landscapes have often focused on enhancing plant diversity
97   (Campbell et al. 2019), sustained flowering (Williams et al. 2015), floral abundance (Campbell
98   et al., 2007; Campbell et al. 2019), and nativity (Salisbury et al. 2015), or various combinations
99   of these aspects (Vrdoljak et al. 2016). Nonetheless, knowledge gaps remain regarding best
100 management practices for insect communities in urban landscapes. The built environment
101 presents landscape architects, designers, and home gardeners with innumerable plant and design
102 choices while simultaneously conferring constraints related to economics, space, community use,
103 native plant commercial availability, and local covenants, restrictions or ordinances.
104
105 In this study, we explored how choices gardeners made in suburban landscape plant community
106 composition influenced the abundance and richness of insects, particularly those known to visit
107 flowers. Our broad hypothesis was: Suburban gardens and yards are habitats for insects. Plant
108 composition in those habitats affects recruitment/presence of wildlife, including insects and
109 pollinators.
110
111 With the following sub-hypotheses:
112
113   1. Insect and flower visitor richness (number of families) and abundance will increase as the
114   number of species of plants increases
115   2. For maximum insect abundance and richness, native plants are best, followed by Florida
116   Friendly plants. Non-native plants are the least beneficial for maximizing insect
117   abundance and richness.
118   3. Insect and flower visitor richness and abundance will increase as the number of blooms
119   increase
120
121 The 'Florida Friendly' designation in sub-hypothesis 2 was based on the Florida-Friendly
122 Landscaping™ Program, which was enacted by the Florida Legislature in 2009 in partnership
123 with University of Florida/IFAS Extension Service, the Florida Department of Environmental
124 Protection, and the five Water Management Districts of Florida (Momol and Tolbert, 2009). This
125 program encourages homeowners to think about their yards' conservation impact and to select
126 plants that have minimal negative impact on the environment. It uses nine criteria centered
127 around watering, pesticides, fertilizers, wildlife habitat, and other issues identified as important
128 through UF/IFAS research efforts (UF/IFAS Florida-Friendly Landscaping Program, n.d.).
129 UF/IFAS has assessed plants as potentially Florida Friendly by using literature-based risk-
130 assessment tools and making regular updates to their recommendations as needed.
131
132 To answer these questions, we conducted plant and insect biodiversity surveys at 34 separate
133 garden sites in North-Central Florida for two years. Since the gardens were privately owned, we
134 did not manipulate any variables within the sites. We focused on these questions because they
135 involved variables that interested landowners could potentially control in suburban landscapes.
136
137
138

Materials & Methods

Study sites

We conducted field portions of study in Alachua County in the North Central region of Florida within and surrounding the city of Gainesville. It is classified as zone 9a on the USDA plant hardiness zone map and as humid subtropical (Cfa) according to the Köppen–Geiger climate classification system (Kottek, et al. 2006).

We studied 34 separate residential urban gardens. Our research was survey-based and our unit of measurement was the entirety of each site's yard. We conducted surveys at the sites over a 21-month period from March 2013 – Dec 2014. Access was granted by participating homeowners.

To identify potential study properties, we broadly disseminated a call for study participants by direct email, newsletter posts, and meeting presentations targeting University of Florida IFAS Extension Agents, Master Gardeners, the Sierra Club, the Florida Native Plant Society, the Audubon Society, and the Florida Trail Association. We also used the property address search function on the Alachua County Property Appraiser's website to identify neighborhoods that were viable candidates based on the size and number of eligible parcels, and then reached out to local homeowners associations in those areas (see Supplementary Information: Initial email sent to solicit participants).

Once a homeowner replied, indicating interest and willingness to participate, we verified the parcel size from the Alachua County Property Appraiser's website and conducted a site visit to visually assess the potential property. Homes with swimming pools (which take up a majority of the yard), locked gates, or large dogs on the property that might create access or safety issues were excluded from consideration. We only considered homes with lot sizes between 0.10 to 0.20 hectares. This was considered a conservative range of typical suburban residential lot sizes in Gainesville, Florida. In order to ease the selection process, we did not consider the demographics of garden owners. The homeowners of all selected properties were asked to sign a property access agreement prepared by the University of Florida's Office of the Vice President and General Counsel.

We strove to include properties that varied in composition and structure, so we selected yards that varied in terms of plant richness and nativity. Some yards were more conventional, with a few primarily ornamental, non-native accent plants. Other yards were more naturalistic, with higher abundances and diversity of native and Florida-Friendly Landscaping™ (FFL) designated species. Each yard varied; we did not have replications of each group along the gradient.

Residential yards were also selected along a gradient of distance to green space. Greenspace was defined as a park, preserve, conservation area/easement, botanical garden, greenway, or undeveloped land. We measured the linear distance from each property to the nearest greenspace using ArcGIS. We noted the log-transformed acreage of the nearest greenspace for each site. Size (square acres) and distance to nearest greenspace were included as separate variables in model testing.

185 Based on these criteria, we chose 34 residential properties from a pool of over 60 homeowners
186 who indicated interest in participating. Although these sites were not randomly sampled, the
187 number of samples and variance in composition and structure mimics typical suburban to urban
188 gardens around North Central Florida. Once a property was selected, all participants signed a
189 legal release allowing researchers to access their yard as needed. This release detailed the goals
190 and duration of the research study, what researchers would be doing, which types of data would
191 be collected, the frequency and duration of visits, and informed homeowners that they could
192 withdraw their permission/participation at any time (see Supplementary Information:
193 Homeowner Permission to Access Property).
194
195 *Vegetation Survey Protocol*
196
197 We conducted two different vegetation surveys for each residential yard: a comprehensive
198 vegetation survey and a flowering plant total bloom count. Exact dates of surveying varied,
199 depending on scheduling and weather. Due to the subtropical climate of our study location,
200 vegetation sampling could be viably conducted on a year-round basis.
201
202 We conducted a comprehensive vegetation survey of each residential yard once per year in
203 January 2013 and February 2014. For this, we systematically recorded every plant species in the
204 front and back yard (except for one property where the homeowner elected to only allow their
205 front yard to be surveyed). All plants were identified using floral morphology or non-floral
206 characteristics (e.g., leaf morphology) if the species was not in flower at the time of the survey.
207 Because of the subtropical climate in our study system, most plants were present during these
208 months, though not necessarily blooming. Due to study limitations (labor constraints, minimizing
209 time spent in homeowner backyards) and the logistical considerations of quantifying plant counts
210 for ground covers and vines, we focused our data collection on presence/absence of plant
211 species. Our comprehensive vegetation assessment provided a "baseline" of plant richness and
212 diversity of plant species for each property. Rather than determining exact area coverage for each
213 species, we decided that a bloom count was the most quantifiable way to assess correlations
214 between blooming species and flower visitors.
215
216 The second vegetation assessment method was a total bloom count. We recorded each plant
217 species in flower and the corresponding total number of blooms four times per year. We
218 surveyed four times in 2013 (May, July, September, and January) and three times in 2014 (May,
219 July, and September). All flowers were counted on every blooming plant within the yard. We
220 counted individual florets as blooms; consequently, compound flowers counted for multiple
221 blooms. We did this for all species except Asteraceae, which were sampled at the level of the
222 capitulum as in Hicks, et. al. 2016. This method was used to streamline the bloom counting
223 process, which included over 700 species. We collected data for bloom richness and bloom
224 abundance because educational materials for gardeners recommend planting flowers to attract
225 pollinators (UF/IFAS Florida-Friendly Landscaping Program, n.d.; Campbell et al., 2019). While
226 flowers are primarily often planted to attract pollinators, they may also provide valuable habitat
227 to non-pollinating insects. On a biological level, blooms can provide refugia for non-flower
228 visitors, or draw in pollinators for predatory insects to consume (Mahr, 2014). For this reason,
229 we included bloom counts in our models for both flower visiting insects and for total insects.
230

231   We identified all plants to the lowest taxonomic level possible, including hybrid species. Field
232   technicians were provided a simplified plant identification guide. This guide consisted of full
233   color plant pictures along with species names and was developed in consultation with the
234   primary investigator. When a confirmed identification was not possible in the field, we
235   photographed the plant and later verified it in the laboratory. Lab identifications were made
236   using Wunderlin's *Vascular Plants of Florida* and identification by the primary investigator.
237
238   Following taxonomic identification, we subsequently categorized each plant as "Florida
239   Friendly," "Native," or "Non-Native" (including native/non-native variants within a genus).
240   "Florida Friendly" status was based on the Florida-Friendly Landscaping™ Program. We used
241   the UF/IFAS searchable database of Florida Friendly plants to make this designation. It should
242   also be noted that the Florida Friendly designation includes both native and non-native plants.
243   Plants that were not considered "Florida Friendly" were designated as either Florida native or
244   non-native using the Guide to the Vascular Plants of Florida, 3rd Edition by Richard P.
245   Wunderlin (2003) and the USDA PLANTS database (National Plant Data Team, 2020).
246
247   *Insect Survey Protocol*
248
249   To sample insect abundance and diversity, we deployed pan traps twice per month from March
250   to December in each of the two project years. Exact dates varied among properties due to
251   inclement weather and scheduling factors.
252
253   The pan traps each consisted of one 0.35 L white, blue, red, and yellow plastic bowl. Two traps
254   were deployed per property per insect survey. We placed the first trap in the front yard and the
255   second in the backyard at ground level in open areas. Trap placement was random. We mixed 15
256   ml of unscented, uncolored dish detergent per 3.81 L of water and filled each bowl to capacity
257   with the soapy water solution.
258
259   Following deployment, all pan traps remained in the field for 24 hours before being collected.
260   During collection, we poured each individual bowl into an 8-12 cup coffee filter set inside a
261   stainless-steel mesh strainer to remove the insect specimens. We placed samples from each bowl
262   in individual sealed plastic bags. All bags were labeled with the property address, date of
263   collection, and bowl color. We subsequently placed all resulting samples in a -28ºC freezer for
264   later processing and taxonomic identification. To prepare a sample for insect identification, we
265   removed each bag from the freezer and allowed it to thaw. We gently washed all insect
266   specimens off of the coffee filter and into a labeled vial using a squeeze bottle of ethanol. Once
267   complete, we topped off the vial with additional ethanol.
268
269   We used a Leica S6D microscope to identify insects. We identified insects to a family level
270   using Borror and DeLong's *Introduction to the Study of Insects* and other taxonomic keys (see
271   References for Insect Identifications). Due to time constraints, we did not identify insects to a
272   narrower taxonomic level across both study years. We stored our samples with the Department
273   of Entomology and Nematology at the University of Florida.
274
275   We subset our insect data to include a 'flower visiting insect' category. Floral visitors
276   are "organisms that visit flowers for nectar or pollen but may or may not pollinate certain plant

277 species" (Campbell et al., 2007). We used literature citations to define insects as a flower visitor
278 or non-flower visitor based on records of adult behavior for either all or a portion of a family (see
279 References for Insect Identifications). All bees and lepidopterans were included as flower
280 visitors (except for bee and lepidopteran families without functional mouthparts).
281
282 *Analyses*
283
284 We used R version 3.6.3 for all analyses (R Core Team, 2020). We compared plant survey data
285 to insect survey data. Plant surveys were always conducted within 14 days of an insect survey.
286
287 We created general linear mixed models for insect abundance, insect richness, flower-visiting
288 insect abundance, and flower-visiting insect richness using the lme function in R. We square
289 root transformed insect abundance and flower-visiting insect abundance in order to better meet
290 the model assumptions. We accounted for differences between our 34 sites by adding site name
291 and sampling date as random effects.
292
293 Our candidate models' explanatory variables included: plant richness (total richness as well as
294 Florida Friendly, native, and non-native plant richness), bloom abundance (total abundance,
295 Florida Friendly, native, and non-native bloom abundance), bloom evenness, bloom richness
296 (total as well as Florida Friendly, native, and non-native bloom richness), site acreage, distance
297 to the closest park, and the log of the acreage of the closest park. We calculated evenness as Evar
298 (Smith and Wilson, 1996). Evar ranges from 0 to 1, where 0 is minimum evenness and 1 is
299 maximum evenness. We checked that our biological explanatory variables (plant richness, bloom
300 abundance) were not correlated to site size, distance to park, or size of nearest greenspace using
301 simple linear regression. We checked that outliers were not driving bloom patterns by removing
302 days with unusually high bloom counts and comparing the results with data that did not have
303 outliers removed. The outliers had no significant effect. Similarly, removing rows of data where
304 evenness = 1.0 (which is unusual and can also mean a complete absence of blooms) did not
305 change our findings.
306
307 We created a list of *a priori* candidate models with different combinations of potential
308 explanatory variables and then ranked and compared them using the aictab function from the
309 AICcmodavg package.
310

311 We generated graphs using the ggplot2 package. To assess the relative strength of different
312 variables, we used the Stats version 6.3.6 package to calculate Pearson's correlation coefficient
313 for each factor in the models (Majewska and Altizer, 2020). In cases when models contained
314 interactions, we graphed the interactions in 3-D using the rms, lattice, and Hmisc packages as in
315 Gezon et al., 2018.
316
317 **Results**
318
319 *General characteristics of sampled data*
320
321 Of the 34 sites selected, average site distance to green space was 1086.9 m, with a range of 0.02
322 m to 3039.13 m and median of 1017.3 m. The log acreage of nearby greenspaces varied from

323   0.30 to 1.76 ha (mean = 0.67 ha, median = 0.40 ha), which translates to 0.0000059 to 285.18 ha
324   (mean = 0.018 ha, median = 0.0001 ha), while the sites selected ranged from 0.08 – 0.33 ha
325   (mean acreage = 0.15 ha, median = 0.14 acres).
326
327   After 21 months of sampling, we had a total of 247 insect surveys paired with the closest plant
328   survey. Within this dataset, we identified 774 species of plants. Plants were somewhat closely
329   distributed among native, non-native, and Florida Friendly species at 36.7%, 38.3%, and 25.0%,
330   respectively (the percentage is slightly less than 100% due to a small number of unlabeled
331   plants). Average plant richness was 29.22 plants per garden per survey (min = 1, max = 211,
332   median = 20). We counted 485,827 blooms. Of these 485,827 blooms, 12 species made up 45%
333   percent of blooms counted (*Fig. 1*). Blooms varied by sampling session, with a median of 883.0
334   blooms, an average of 1,966.9 blooms, and a range of 0 to 21,632 blooms. Bloom evenness
335   averaged 0.24, with a median of 0.21 and range from 0.04 to 1.00.
336
337   Our insect surveys yielded 34,972 insects. On average 141.6 insects were collected from each
338   garden site per survey (range = 2 to 540, median = 124). Insects represented 251 families and
339   five orders (*Fig. 2*). The family "Dolichopodidae" from the insect survey dataset was
340   superabundant, consisting of almost 50% of the insect abundance count and creating outliers in
341   the data. However, removing it from the data did not make any difference in the top models, so
342   we kept the family in the final analyses for total insects. Dolichopodidae were not included in
343   analyses for flower visitors as they were not considered flower visitors.
344
345   Sub-hypothesis 1: Insect and flower visitor richness (number of species) and abundance will
346   increase as the number of species of plants increases
347
348   Counterintuitively, higher plant richness was not associated with higher insect abundance or
349   richness (*Tables 1 and 2*). Insect abundance and insect richness were both slightly negatively
350   correlated to plant richness.
351
352   Sub-hypothesis 2: Native plants > Florida friendly plants > non-native plants
353
354   There was no clear indication that a certain designation of plant type resulted in higher insect
355   abundance or richness (*Tables 1 and 2*). As seen in the ranked AICc tables in *Table 1*, we
356   created models that had plant abundance and richness separated by type as well as models that
357   had them not separated. In both cases, total plant richness was included in the models, but plant
358   richness as divided by type was not.
359
360   Sub-hypothesis 3: Insect and flower visitor richness and abundance will increase as the number
361   of blooms increase
362
363   Blooms were positively correlated to flower visiting insect abundance (*Table 2, Fig. 3*). While
364   graphs indicated a positive correlation to additional dependent variables, bloom abundance alone
365   was not significant in many of our top models (*Table 2*). Instead, other models found that bloom
366   evenness had a strong, positive modulating impact on bloom abundance, and bloom
367   evenness*bloom abundance were positive and significant for insect abundance and richness (*Fig.

368 *4* and *Fig. 5*). In general, insect abundance and richness increased most when bloom abundance
369 and bloom evenness both increased (*Table 2*).
370
371 Additional finding: Bloom evenness affected insect abundance and richness
372
373 Bloom evenness had a strong, positive modulating effect on bloom abundance for both insect
374 abundance and insect richness (*Table 2*, *Fig. 4* and *Fig. 5*). In other words, as bloom evenness
375 increased, the same number of blooms had a far larger positive impact on insect abundance and
376 richness than they would have had with an uneven bloom distribution.
377
378 *Non-significant factors*
379
380 Plant type (native, non-native, and Florida Friendly plants), distance to green space, and green
381 space size (*Table 1*) proved to be unimportant, and models that included them were not the top
382 models selected. We accounted for variability between sites by setting site location and date as
383 random effects in all of our mixed models.
384
385 **Discussion**
386
387
388 Sub-hypothesis 1: Insect and flower visitor richness (number of species) and abundance will
389 increase as the number of species of plants increases
390
391 We hypothesized that plant richness would have a large, positive relationship to insect
392 abundance and richness. To our surprise, higher plant richness was slightly negatively associated
393 with total insect abundance and richness. Specifically, our models found plant richness to be
394 significant, but with a weak, slightly negative relationship with insects (*Table 2*). For flower
395 visiting insects, the top models divided plant richness among Florida Friendly plants, native
396 plants, and non-native plants, but only Florida Friendly plants were significant, and they too
397 were slightly negatively correlated (*Table 2*).
398
399 Other literature notes the unclear nature of the relationship between plant richness and insect
400 populations. Ebeling et al. (2008) mentioned that other field studies have found variable impacts
401 from plant richness on pollinators, but their study, which involved highly controlled test plots,
402 found a strong correlation. Studies by Majewska and Altizer (2020), Ebeling et al. (2008),
403 Haddad et al. (2001), and Wright and Samways (1998) also found a positive relationship.
404
405 One possible explanation is that some taxa may be more affected than others. Smith et al. (2006)
406 found that plant richness affected solitary bees and hoverflies, but not solitary wasps or
407 bumblebees. Another potential reason is that all plants are not created equal. Certain plant
408 species may be exceptionally valuable to insects, while other plants have a negligible effect
409 (Ebeling et al., 2008; Frankie et al., 2005). For example, Ebeling et al. (2008) planted 60 unique
410 plant species, but only 32 of them were visited by flower-visiting insects. Of those 32 popular
411 plant species, a single especially attractive species got about half of all insect visits. When plant
412 richness is maximized, perhaps the more attractive plants are diluted by less influential plants.
413

414 Because our study was based on observations rather than manipulated experimental plots, it is
415 impossible to completely eliminate confounding factors. Important interactions would likely still
416 appear despite these compounding factors, but moderate to slight factors might get lost.
417 Alternately, perhaps evenness and plant abundance have a relationship. Because our
418 comprehensive vegetation survey only noted the presence or absence of a given plant species, we
419 were unable to collect evenness and plant abundance information for the total plant count, but
420 it's possible that having a number of the same species has a magnifying effect similar to what we
421 saw with bloom evenness and abundance. If a site has 200 species of plants, but 100 of those
422 species are a single individual, the effects of those low-abundance species may be negligible. We
423 recommend further research on a potential interaction between plant evenness and abundance to
424 guide plant selection in gardens.
425
426 Sub-hypothesis 2: For maximum insect abundance and richness, native plants > Florida friendly
427 plants > non-native plants
428

429 Our study did not find a clear advantage for insect family richness or abundance when planting
430 native, Florida Friendly, or non-native plants. In some cases, our top models simply did not
431 include the designations, while in other cases the top models included the designations, but only
432 one (typically the Florida Friendly designation) was statistically significant. This result may
433 seem surprising, considering the perception that native plants are the superior choice for a variety
434 of reasons, including local adaptation, hardiness, and attractiveness to native pollinators. Our
435 findings provide a valuable finding for home gardeners: existing non-native plants can be
436 beneficial to insects. Our findings are in keeping with the mixed results of other authors
437 (Majweska and Altizer, 2020; Pardee and Philpott, 2014; Smith et al., 2006; Frankie et al., 2005;
438 Haddad et al., 2001; Matteson and Langelloto, 2011; Burghardt and Tallamy, 2015).
439
440 On one hand, a study involving 36 experimental plots conducted by Salisbury et al. (2015) found
441 that native and near-native treatments received higher pollinator visits than non-native
442 treatments, and a small study on nectarivorous birds found that of four common plants, the two
443 natives produced higher volumes of nectar per floral unit (French, Major, and Hely 2005).
444 Likewise, Mathiasson and Rehan (2020) found that wild bee declines were linked to introduced
445 plant species. On the other hand, a metastudy on gardener plant selection and maintenance
446 choices by Majewska and Altizer (2020) found that native vs. non-native plant selection did not
447 make a significant difference and recommended follow-up on plant selection. Similarly, a study
448 by Staab et al. (2020) on exotic garden plants found that exotic species helped substitute as food
449 resources for pollinators when native plants became seasonally scarce. The truth may be in the
450 middle. A study by Frankie et al. (2005) found that only 9.5% of non-native flowers were
451 actually attractive to bees, but those that were attractive were quite beneficial. This may be a
452 piece to the puzzle: exotic flowers overall may not be bad, but simply less likely to provide food
453 resources for flower visiting insects.
454
455 While the full answer is still unknown, this does not detract from the other benefits of planting
456 native plants. A large body of literature already exists on the benefits of native plants. Planting
457 hardy, well-suited plants minimizes landowner exposure to fertilizer and pesticides, saves time
458 and money on watering, fertilizers, and pesticides, reduces pollution from runoff, conserves
459 water, controls weeds, reduces erosion, and creates wildlife habitat (UF/IFAS Florida-Friendly

460 Landscaping™ Program, n.d., Penn State Extension, 2019). From a research standpoint, more
461 gardening best practices might be found by looking into the effects of host plants on their hosts,
462 expanding on the work of Crowder et al. (2010) and Smith et al. (2006) on predatory and
463 parasitic taxa among native and non-native plants, and expanding research on which plant traits
464 make them more attractive to insects (Ebeling et al., 2008; Grindeland et al., 2005; Akter, Biella,
465 and Klecka, 2017; Ohashi and Yahara, 2001).
466
467 Sub-hypothesis 3: Insect and flower visitor richness and abundance will increase as the number
468 of blooms increase
469
470 Bloom abundance had a strong positive effect on flower-visiting insect abundance. This is in
471 agreement with most literature (Majewska and Altizer; 2020, Ebeling et al., 2008; Pardee and
472 Philpott, 2014; Akter et al., 2017; Matteson and Langelloto, 2011). The strength of the
473 interaction, measured by Pearson's correlation coefficient r, was similar to Majewska and Altizer
474 (2020), who found that flower abundance had a positive effect on insects with an effect size of
475 0.26 (compared to 0.296 for our study).
476
477 Additional finding: Bloom evenness affected insect abundance and richness
478
479 While bloom abundance was important alone, bloom evenness proved to have a surprisingly
480 influential role, strongly modulating the effects of bloom abundance in the top models for Insect
481 Abundance and Insect Richness and appearing in the top three models for Flower-visiting Insect
482 Abundance and Richness. As seen in *Figs. 4, 5,* and *6*, as bloom abundance increased, insect
483 richness and insect abundance also increased modestly. However, when bloom abundance
484 increased in conjunction with increased bloom evenness, insect richness and abundance
485 increased dramatically.
486
487 Insects benefited most from a plant community that had both abundant and evenly distributed
488 floral resources. Flower visitor richness and, even more dramatically, total insect abundance,
489 increased most when more flowers were present with consistently represented blooming plants.
490 It should be noted that complete evenness (Evar = 1.0) was not needed to benefit insects. Our
491 focal properties had bloom evenness values primarily between 0.1596 and 0.2581. However,
492 when blooms approached a near-monoculture, Evar values tended to be very low. Near-
493 monocultures seemed to reduce the effectiveness of high bloom counts; thus it appears that some
494 family richness is still an important consideration for landscapes.
495
496 Our results regarding evenness help fill critical knowledge gaps on the best practices for
497 benefiting insects in urban landscapes. Very few studies on urban and suburban insect
498 biodiversity have focused on evenness. Stavert et al. (2019) found that evenness by itself did not
499 have a huge impact, but it indirectly affected plant reproduction by affecting the structure of
500 plant-pollinator networks. Our own results on evenness by itself were negligible, but the
501 interaction between evenness and abundance indicated a potentially interesting, statistically
502 significant relationship. Additional research on the bloom abundance / evenness interaction could
503 potentially maximize valuable ecosystem services such as pest control and pollination.
504 Landscape architects, urban planners, and gardeners are already working to enhance forage and
505 habitat resources for flower-visiting insects by increasing floral availability (Bellamy et al.,

506 2017; Southon et al., 2017; Li et al., 2017; Todorova, Asakawa, and Aikoh, 2004). When
507 selecting plants, ensuring that different species of flowering plants will provide an even bloom
508 presence could be a low-hanging fruit to increase the impact of plant species purchased.
509
510 Restoration projects would also benefit from increased investigation into the impact of
511 community evenness. Restoration projects already emphasize diversity and native plant selection
512 (Bischoff, Steinger, and Müller-Schärer, 2010; Richards, Chambers, and Ross, 1998; Stanley,
513 Kaye, and Dunwiddie, 2011). This approach has been successful, with Bischoff, Steinger, and
514 Müller-Schärer (2010) finding that high genetic diversity resulted in more productive plant
515 populations with less risk of failing to establish. Observational studies on bloom evenness and
516 bloom abundance could provide another metric for evaluating these projects. If an interaction is
517 found, future restorations could maximize impact by prioritizing not just the total number of
518 blooming plant species introduced, but also ensuring that the numbers planted provide an even
519 spread of available resources. Furthermore, insects are seldom considered with habitat
520 restoration projects and methods that include measuring evenness could assist in combatting
521 insect and pollinator declines.
522
523 *On the study location*
524
525 Our study helps fill a literature gap on urban and suburban biodiversity in the Southeast United
526 States. Most studies on urban garden habitat features and insects have been in mild to cold mid-
527 latitude climates (Majewska and Altizer, 2020; Ebeling et al., 2008; Frankie et al., 2005;
528 Matteson and Langelloto, 2011; Pardee and Philpott, 2014; Philpott et al., 2014; Smith et al.,
529 2006). Our study took place in Florida, which has a humid subtropical climate (Cfa) (Kottek et
530 al., 2006). The differences in seasonality may be significant. Most temperate climates have
531 distinct seasons, and many plants and animals go into diapause or die off each winter (Powell
532 and Logan, 2005). By contrast, our study site was primarily affected by two periods of growth
533 dictated by rainy and dry seasons. This difference in seasonality resulted in differences between
534 bloom periods and insect activity (Wolda, 1988; Lechowicz, 1995; Shimadzu, 1998). This in turn
535 may have affected plant availability, resulting in a larger plant pool for homeowners to select.
536
537 *Insignificant factors*
538
539 Contrary to our expectations, distance to green space and the size of the nearest green space did
540 not influence the population of flower-visiting insects. Majewska and Altizer (2020) found that
541 many studies identified a correlation between distance to various habitats and green space, but
542 studies have also found that that landscape level factors tended to have weaker associations with
543 insects than within-garden features (Majewska and Altizer, 2020; Philpott et al., 2014; Pardee
544 and Philpott, 2014; Williams and Winfree, 2013). For example, Majewska and Altizer (2020)
545 and Philpott et al. (2014) found that landscape level factors (such as distance to agriculture,
546 distance to water, or distance to forest) were relevant, but tended to have weaker associations
547 with pollinators than within-garden features. In other words, external factors beyond one's
548 control, such as the size of the nearest park, are less important than the choices one makes with
549 plant selection.
550

551   We also found that site size did not influence insects. However, as we selected suburban lots
552   within a set range of sizes these conclusions are quite limited. By contrast, Majewska and Altizer
553   (2020) found garden size was important for insects. This difference in findings reveals an
554   opportunity for future research to explore larger datasets with a range of yard sizes. Yet, our
555   findings provide encouraging support for the impact homeowners can have with the factors they
556   have control over in their yards, as yard size is less flexible or easy to change.
557
558   *Limitations*
559
560   There were some limitations to our study regarding plant abundance, timing, trap types, and
561   species identifications. We did not include plant species abundance because our baseline
562   vegetation surveys only recorded presence/absence of a given species and our bloom surveys did
563   not include plant abundance counts. Thus, our vegetation surveys yielded only total plant
564   richness and total bloom abundance. Ideally, we would have had time to also include data
565   collection on plant abundance.
566
567   We were also limited by scheduling logistics: ideally, the insect and vegetation surveys should
568   be collected on the same day. However, we conducted our insect and vegetation surveys on
569   different days and then matched our insect surveys to the closest vegetation sampling day. Since
570   most of the plants in our study bloomed for more than two weeks (UF/IFAS, n.d.), we feel
571   confident that we still got an accurate assessment of what plants were blooming around when we
572   collected insects, but same-day surveys would have been preferrable.
573
574   We also only used bowl traps for insect surveys due to the use of homeowners' private
575   properties. These were deemed sufficient for the study since bowl traps are a widely known,
576   widely recommended, and effective method for sampling flower visitors (Grundel et al., 2011;
577   O'Connor et al., 2019; Westphal et al., 2008). Nonetheless, we may have been able to capture
578   more insects with a wider array of techniques, such as malaise traps or sweep netting. We also
579   did not account for the following variables: bare ground, water sources, unmowed areas, canopy
580   cover, and pesticide applications.
581
582   Another limitation that would have added to the study was identifying insects to species level.
583   Due to the volume of insects collected and labor available, we only identified insects to the
584   family level across both years. This allowed us to identify flower visiting insects and general
585   trends across families and orders. However, species richness is the more commonly used metric,
586   and we were not able to determine which flower visiting insects were native, an important sub-
587   classification. Native pollinators have experienced severe declines over the past several decades,
588   and there is great interest (among both the public as well as scientific communities) and value in
589   finding which variables will most help native pollinators (Potts et al. 2010; Forister et al. 2019;
590   van Klink et al., 2020; Mathiasson and Rehan, 2020). Future studies of plant-pollinator
591   interactions could benefit by identifying insect flower visitors to a lower taxonomic level.
592
593
594   **Conclusions**
595

596 Insect populations are declining globally (Cardoso et al., 2020; van Klink et al., 2020). We
597 conducted this study with the goal of increasing our understanding of which suburban landscape
598 factors contribute most to attracting pollinator and insect populations in order to help inform
599 plant choice and related landscaping decisions.
600
601 We found that homeowners can enhance the insect richness of their backyard habitats by
602 planting more blooming plants with an even selection of species. More blooms were clearly
603 associated with more flower visitors, and the evenness of the blooms significantly modulated the
604 effectiveness of bloom abundance. Planting even, abundant flowering plants of diverse species
605 will have a much greater impact on attracting insects than planting the same number of just one
606 species. Very few studies on urban insect biodiversity have focused on evenness, so finding that
607 the two were related expands the literature on this topic. Our results have the potential to be
608 applied more broadly to other landscapes within the built environment by landscape architects,
609 urban planners, and land managers.
610
611 Native, non-native, and Florida Friendly plant designations were not important in this study.
612 Although the best fit models found no clear distinction between these three types of plants, other
613 benefits of native landscaping remain substantial. Instead, gardeners can conclude that their
614 existing non-native plants may still provide vital resources to flower visiting insects.
615
616 Our study highlighted opportunities for additional research. Our study was not focused on a scale
617 to enable comparisons between individual plant taxa. Future studies might result in flower
618 abundance guides to help decision makers find the ideal plant abundance and distribution.
619 Likewise, both our findings and literature on plant richness were unclear. An interaction term
620 between plant abundance and evenness may exist that explains the variable effects of plant
621 richness.
622
623 When a suburban homeowner sets out to augment or landscape their yard there are many limiting
624 factors they must consider, as well as factors out of their control. We found that two factors
625 under their control- choosing flowering plants and planting even numbers of these plants- were
626 more influential than other external factors such as nearby greenspaces. Specifically, we found
627 that when bloom abundance and evenness increased simultaneously, there were positive, non-
628 additive effects on flower-visiting insects. The results of our study show that homeowners can
629 make simple changes to their landscaping decisions that will dramatically increase the impact on
630 flower-visiting insects without an increase in cost or labor.
631
632
633
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641

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656
657
658

659   **References**

660

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Figure 1

Cumulative bloom count by most common plant species

Figure 1 displays the cumulative bloom count for each plant throughout the course of the study. The top dozen species of plants dominated bloom counts by both number (see left-hand y-axis label) and percentage (see right-hand y-axis label).
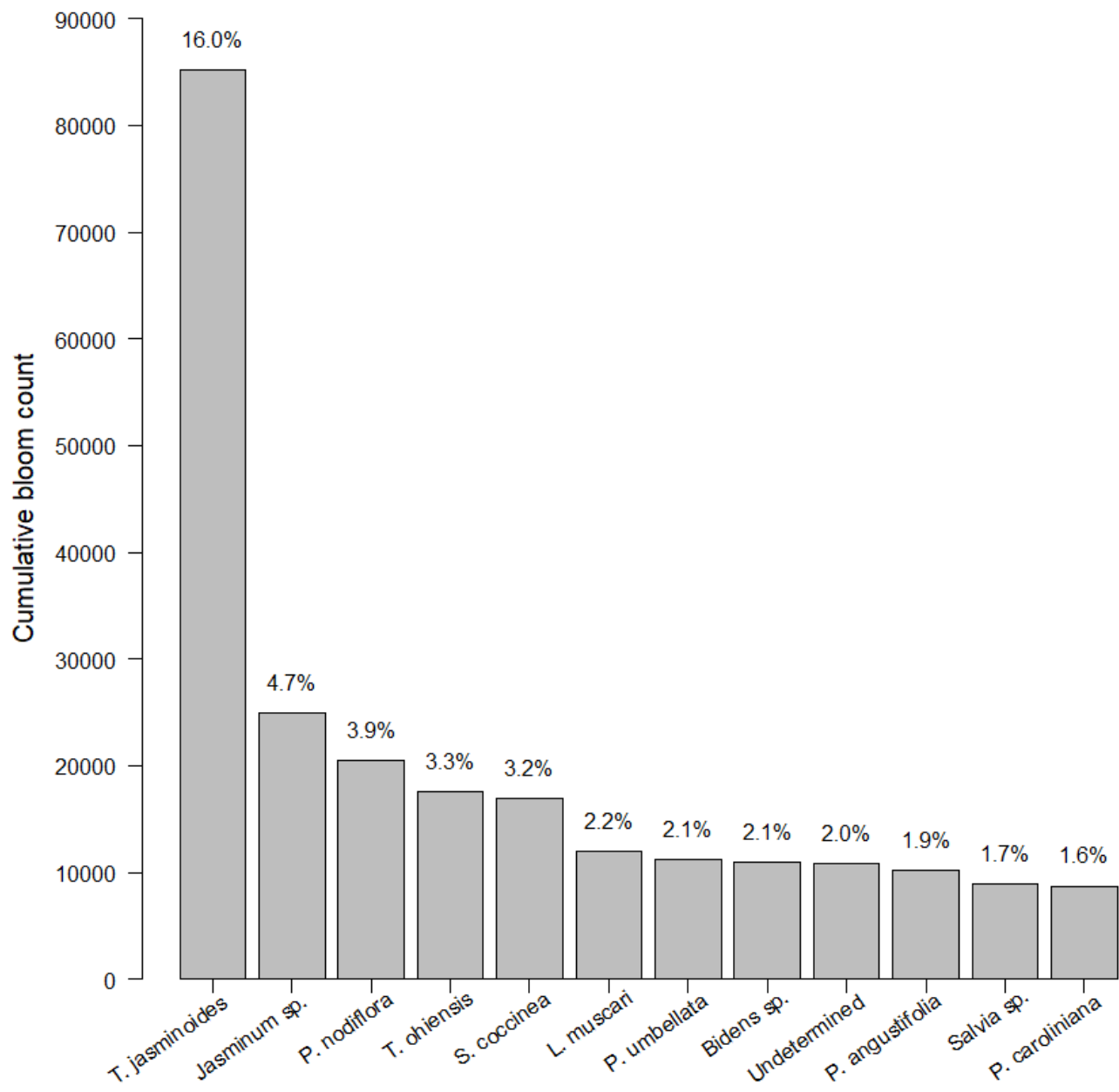
Figure 2

Insect abundance by order

Figure 2 displays the total summed insects counted for each order throughout the course of the study. The left-hand y-axis displays the count while the right-hand y-axis displays the percentage.
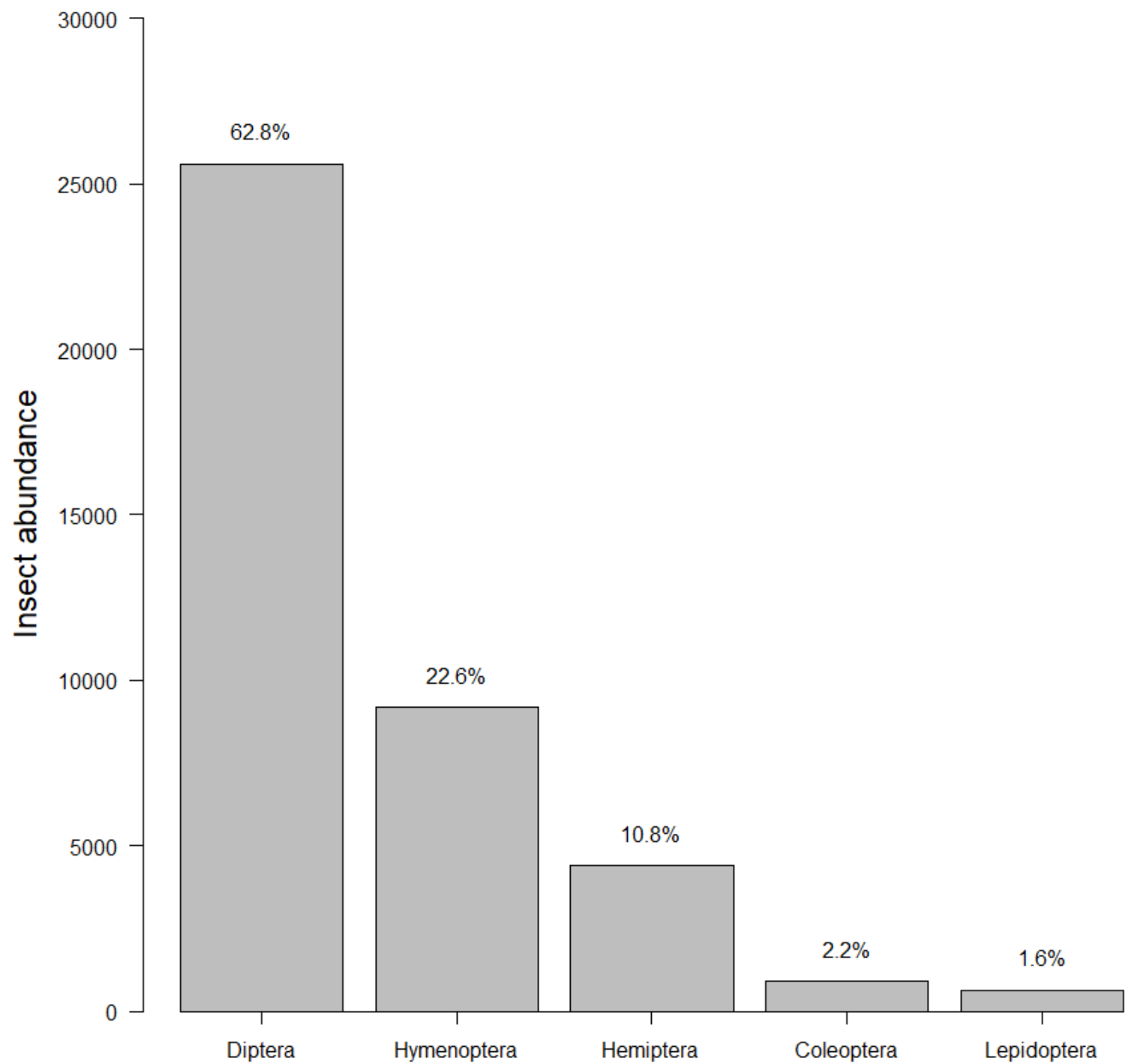
Figure 3

Correlation between dependent variables and bloom abundance

Scatterplots of the relationship between total bloom abundance (per site, per day) and A) total insect abundance; B) total insect richness; C) flower visitor abundance; D) flower visitor richness.
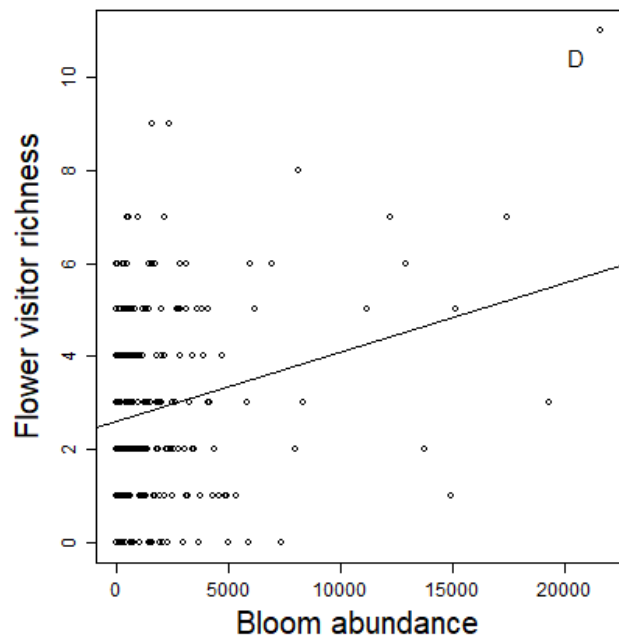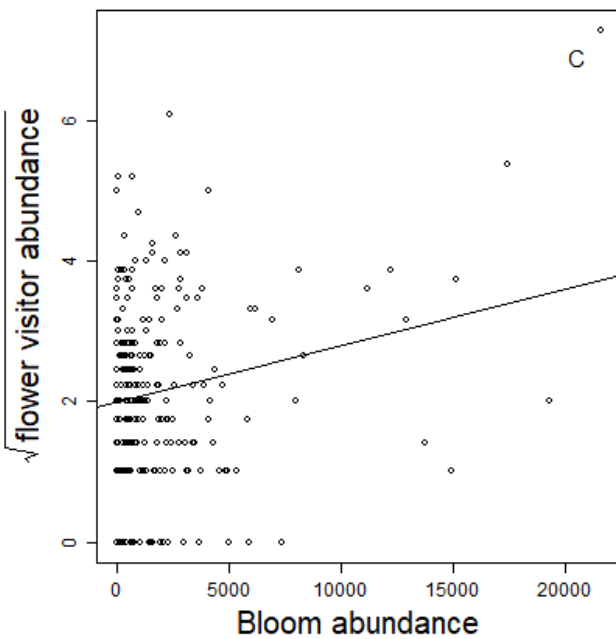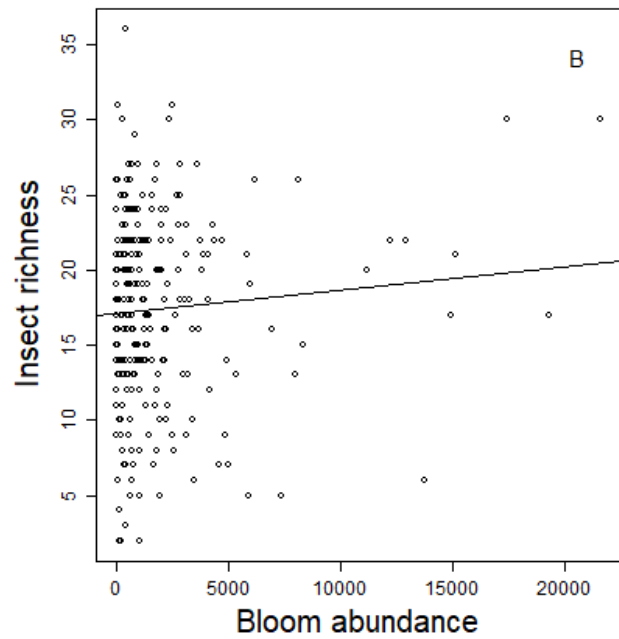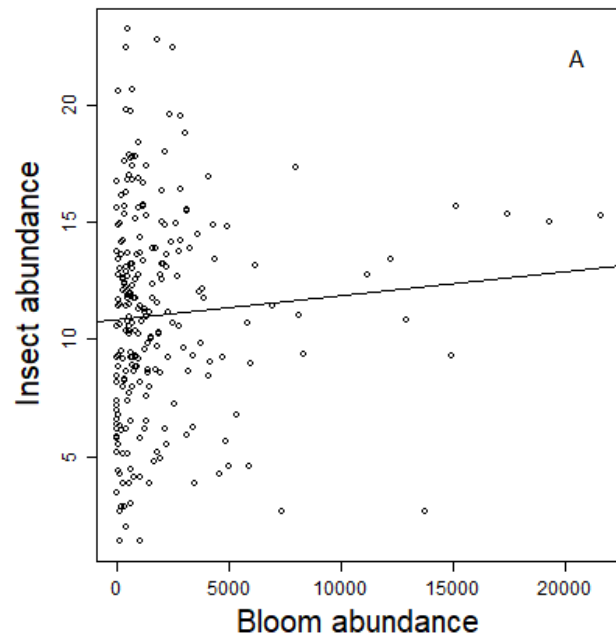
Figure 4

Interaction between bloom abundance and bloom eveness for y = sqrt(Insect Abundance).

On the x-axis is bloom abundance (in number of blooms) from 0 to 30,000 blooms. The bloom abundance axes were capped at 30,000 to make the graph easier to read. On the y-axis is the square root of insect abundance counted at each site per day. On the z-axis is bloom evenness, measured by Evar from 0 to 1.0, where 0.0 = no evenness and 1.0 = a perfectly even community. This graph indicates that bloom abundance alone did not have a clear correlation to insect abundance when evenness was low. However, as evenness increased, bloom abundance showed a strong and positive correlation with insect abundance.
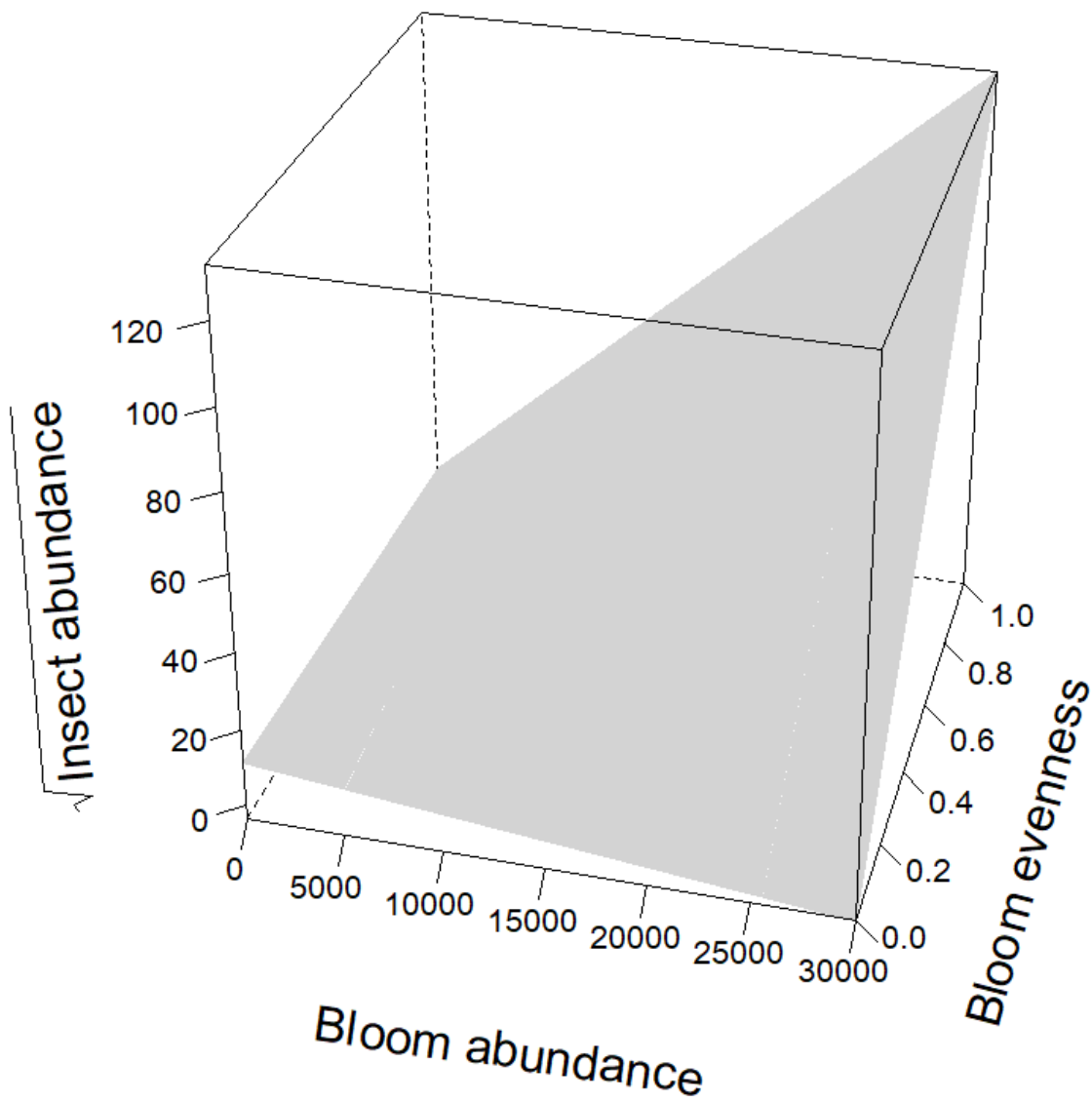
Figure 5

Interaction term between bloom abundance and bloom evenness for y = insect richness).

On the x-axis is bloom abundance (in number of blooms) from 0 to 30,000 blooms. The bloom abundance axes were capped at 30,000 to make the graph easier to read. On the y-axis is total insect richness (the number of separate species of insects) counted at each site per day. On the z-axis is bloom evenness, measured by Evar from 0 to 1.0, where 0.0 = no evenness and 1.0 = a perfectly even community. This graph indicates that bloom abundance alone did not have a clear correlation to insect richness when evenness was low. However, as evenness increased, bloom abundance showed a strong and positive correlation with insect abundance.

Total insect richness

80

60

40

0

5000 10000 15000 20000 25000 30000

Bloom abundance

1.0

0.8

0.6

0.4

0.2

0.0

Bloom evenness
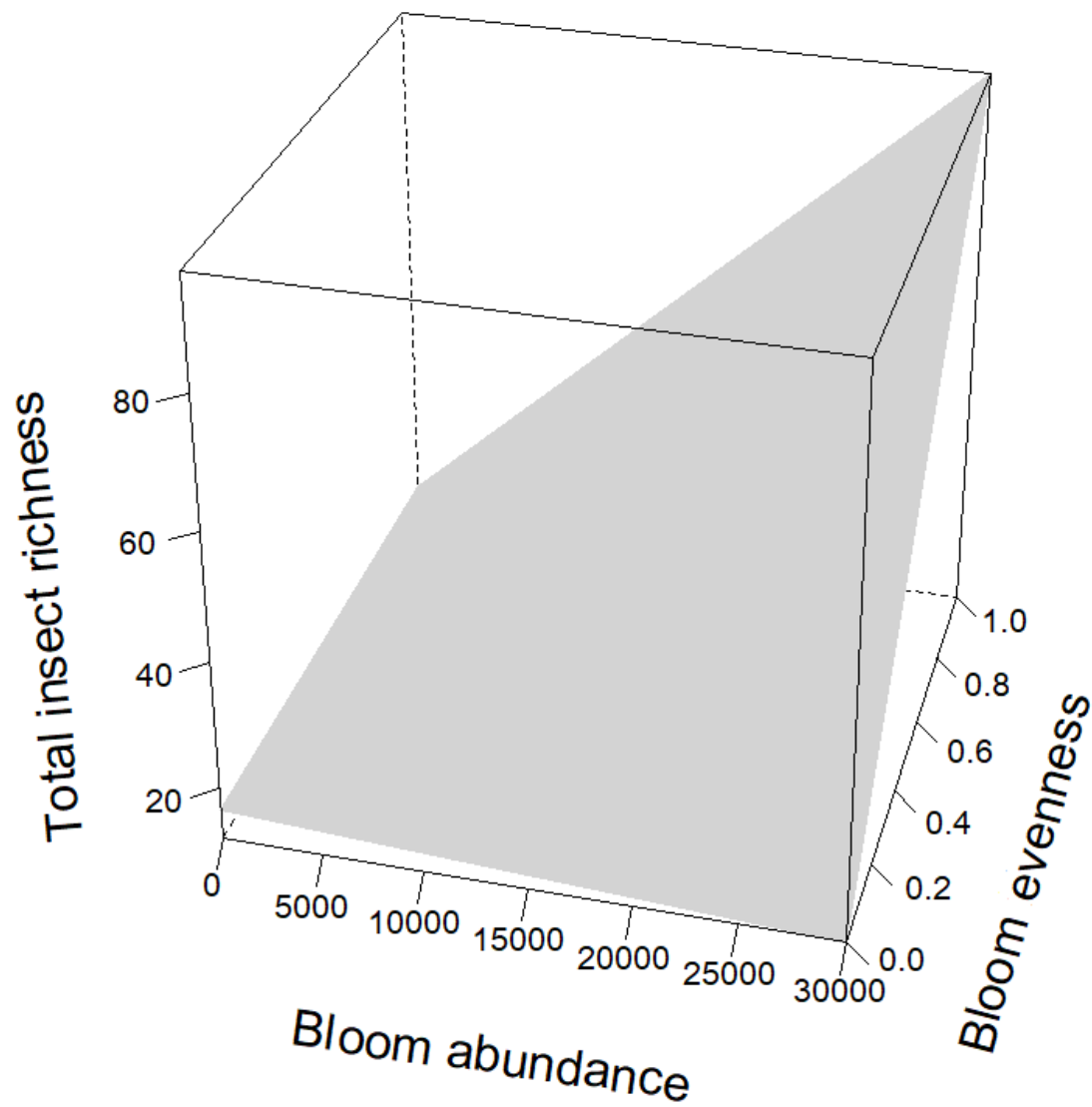
Table 1: Model selection statistics for the garden variables and landscape factors affecting four measures of insect community: (a) Insect Abundance, (b) Insect Richness, (c) Flower-visiting Insect Abundance, (d) Flower-visiting Insect Richness

The models tested were general linear mixed models, with the exception of (d) Flower-visiting Insect Richness, which was a generalized linear mixed Poisson model. Abundance of Flower-visiting Insects and Insect Abundance were square root transformed. We tested seven to twelve models for each response variable. The top three models (or however many resulted in an AICc cumulative weight of 90%) for each response are listed below.

Plus signs indicate that a positive relationship was found, while negative signs indicate a negative relationship. Blank spaces indicate a lack of statistically significant relationships (p > 0.05).

Each model ended with the code, *"random ~1|Site.name/Date.veg.survey/Date.bowl.survey/bloom.date/Date.veg.survey/Date.bowl.survey/bloom.date, method = "ML"*, which added the mixed effects of site location and sample dates. The exception was the Poisson model for (d) Flower-visiting Insect Richness, whose syntax required additional parentheses and did not include sample dates due to model singularity errors.

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Key

K = number of parameters in the model

d.f. = degrees of freedom

AICc = Akaike weights

Delta AICc = Change in Akaike weights

w_i = Akaike weights cw_i = cumulative Akaike weights

log L = log likelihood

Response (model)	K	d.f.	AICc	ΔAICc	w_i	cw_i	Bloom Abundance	Plant Richness	Fl. friendly plant richness	Native plant richness	Nonnative plant richness	Fl. Friendly bloom abundance	Native bloom abundance	Nonnative bloom abundance	Bloom evenness	Bloom abundance*bloom evenness	Bloom richness
(a) Insect Abundance																	
	10	209	526.24	0.00	0.99	0.99		-								+	
	13	206	537.21	10.97	0.00	1.00	+			-							
	8	211	539.07	12.83	0.00	1.00		-									
(b) Insect Richness																	
	10	209	1616.24	0.00	0.35	0.35		-								+	
	9	210	1616.57	0.33	0.29	0.64				-	+						
	8	211	1618.52	2.28	0.11	0.75		-									
	9	210	1619.18	2.94	0.08	0.83	+	-									
	7	212	1619.62	3.38	0.06	0.90		-									
(c) Flower-visiting Insect																	

1 **Table 1: Model selection statistics for the garden variables and landscape factors affecting four measures of insect community:**
2 **(a) Insect Abundance, (b) Insect Richness, (c) Flower-visiting Insect Abundance, (d) Flower-visiting Insect Richness**
3
4 The models tested were general linear mixed models, with the exception of (d) Flower-visiting Insect Richness, which was a
5 generalized linear mixed Poisson model. Abundance of Flower-visiting Insects and Insect Abundance were square root transformed.
6 We tested seven to twelve models for each response variable. The top three models (or however many resulted in an AICc cumulative
7 weight of 90%) for each response are listed below.
8
9 Plus signs indicate that a positive relationship was found, while negative signs indicate a negative relationship. Blank spaces indicate a
10 lack of statistically significant relationships ($p > 0.05$).
11
12 Each model ended with the code, *"random*
13 *~1|Site.name/Date.veg.survey/Date.bowl.survey/bloom.date/Date.veg.survey/Date.bowl.survey/bloom.date, method = "ML"*, which
14 added the mixed effects of site location and sample dates. The exception was the Poisson model for (d) Flower-visiting Insect
15 Richness, whose syntax required additional parentheses and did not include sample dates due to model singularity errors.
16
17 Citation: https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2435.12803
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Abundance																			
	10	209	806.33	0.00	0.68	0.68	+												
	8	211	808.08	1.74	0.28	0.96	+	-											
(d) Flower-visiting Insect Richness																			
	6		988.54	0.00	0.58	0.58	+		-										
	4		990.37	1.83	0.23	0.81	+	-											
	6		990.93	2.40	0.17	0.98		-											

23   *Key*

25   K = number of parameters in the model

26   d.f. = degrees of freedom

27   AICc = Akaike weights

28   Delta AICc = Change in Akaike weights

29   w_i = Akaike weights

30   cw_i = cumulative Akaike weights

31   log L = log likelihood.

Table 2: Coefficients and relative coefficient importance for models analyzing the following response variables: (a) Insect Abundance, (b) Insect Richness, (c) Flower-visiting Insect Abundance, (d) Flower-visiting Insect Richness

The models tested were general linear mixed models. Abundance of Flower-visiting Insects and Insect Abundance were square root transformed. We tested seven to twelve models for each response variable. The coefficients of the top model for each response variable is listed below.

Std. Error = Standard Error

Pearson's r = Pearson's r (a measurement of relative importance. Higher numbers indicate greater importance)

1 **Table 2: Coefficients and relative coefficient importance for models analyzing the following response variables: (a) Insect**
2 **Abundance, (b) Insect Richness, (c) Flower-visiting Insect Abundance, (d) Flower-visiting Insect Richness**
3
4 The models tested were general linear mixed models. Abundance of Flower-visiting Insects and Insect Abundance were square root
5 transformed. We tested seven to twelve models for each response variable. The coefficients of the top model for each response
6 variable is listed below.
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Response (model)	Value	Std. Error	t-value	p-value	Pearson's r
(a) Insect Abundance					
(Intercept)	3.413	0.098	34.853	0.000***	--
Plant Richness	-0.014	0.003	-4.031	0.0001***	-0.157

Bloom Abundance	-0.000	0.000	-2.974	0.003**	0.072
Bloom Evenness	-0.272	0.282	-0.966	0.335	-0.130
Bloom Abundance*Bloom Evenness	0.001	0.000	4.132	0.0001***	0.137
(b) Insect Richness					
(Intercept)	17.69	0.936	18.900	0.000***	--
Plant Richness	-0.117	0.031	-3.747	0.0002***	-0.143
Bloom Abundance	0.000	0.000	-1.058	0.291	0.077
Bloom Evenness	3.402	2.542	1.338	0.182	0.016
Bloom Abundance*Bloom Evenness	0.006	0.003	2.267	0.024*	0.101
(c) Flower-visiting Insect Abundance					
(Intercept)	2.323	0.175	13.295	0.000***	--
Bloom Abundance	0.0001	0.000	3.958	0.0001***	0.198
Florida Friendly plant richness	-0.085	0.032	-2.662	0.008***	-0.095
Native plant richness	-0.025	0.030	-0.831	0.407	-0.058
Non-native plant richness	0.046	0.027	1.691	0.092	-0.061
(d) Flower-visiting Insect Richness					
(Intercept)	3.192	0.271	11.792	0.000***	--
Bloom Abundance	0.000	0.000	4.732	0.000***	0.233
Florida Friendly plant richness	-0.142	0.050	-2.869	0.005***	-0.122
Native plant richness	-0.029	0.046	-0.626	0.532	-0.062
Non-native plant richness	0.057	0.042	1.370	0.172	-0.081

30
31

33   *Key*

35   Std. Error = Standard Error

36   Pearson's r = Pearson's r (a measurement of relative importance. Higher numbers indicate greater importance)